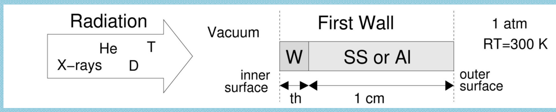
D. Garoz, R. S. Hontoria, J. Alvarez , A. Rivera, R. Gonzalez-Arrabal, and J. M. Perlado

Instituto Fusión Nuclear (DENIM) - Universidad Politécnica Madrid

Temperature Evolution and Light Species Diffusion in Armor and Structural Material for Inertial Fusion Reactor Chambers: a Case for HiPER 4a

Introduction

One of the most advance designs for HiPER fusion reactor is a spherical chamber 10 m in diameter based on dry wall concept. In this system, the first wall will have to withstand short energy pulses of 5 to 20 MJ at a repetition rate of 0.5-10 Hz mostly in form of X-rays and charged particles. To avoid melting of the inner surface, the first wall consists on a thin armor attached to the structural material. Thickness (th) and material of each layer have to be chosen to assure the proper functioning of the facility during its planned lifetime.

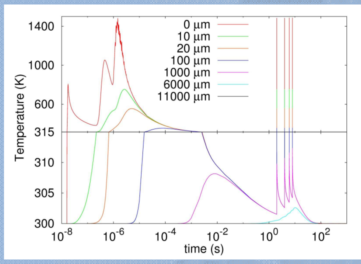


We study the thermo-mechanical response and diffusion of tritium in tungsten coated steels and tungsten coated aluminum under HiPER 4a scenario (bunch of 5 shock ignitions 48 MJ in 10 seconds, 0.5 Hz).

Thermo-mechanical response

Finite element solver ASTER CODE is used to estimate temperature, stresses and deformation in the first wall.

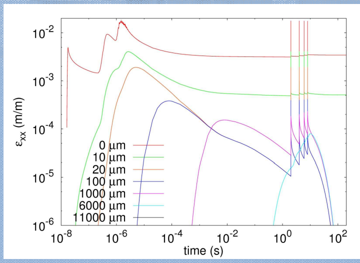
Temporal evolution of the temperature at different depths (d) in a 1 mm W armor attached to 1 cm SS316 structural material.



- The T_{max}< 1400 K on the inner surface is below W melting point.
- T at the armor-structural interface (d=1000 µm) increases with the number of pulses.
- After 5 pulses T decreases to RT in hundreds of seconds.

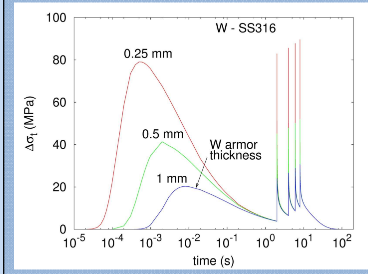
Because of geometrical conditions, the local increase of T generates material expansion with compression stresses tangential to the radiation direction.

Temporal evolution of longitudinal deformation (ε_{xx}) estimated at different depths (W@1mm, SS316 structural material@1cm).

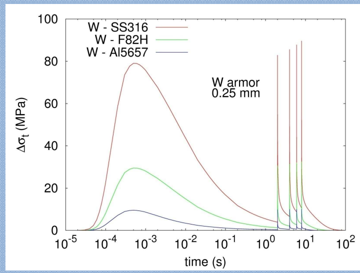


- For d < 20 µm W plastically deforms near the inner surface suffering compression-traction stress cycles. After 5 pulses $\varepsilon_{xx} \neq 0$
- For d > 20 µm material elastically deforms. After 5 pulses $\varepsilon_{xx} = 0$

Because of the different expansion coefficient of each material, there is a discontinuity in the tangential stress ($\Delta\sigma_t$) at the junction interface.



Temporal evolution of discontinuity in $\Delta\sigma_t$ at the junction for different W armor thickness attached to 1cm SS316



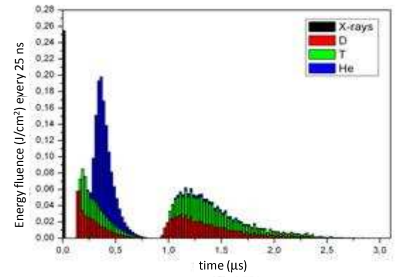
Temporal evolution of discontinuity in $\Delta\sigma_t$ at the interface for different structural materials (W@0.25mm structural materials@1cm).

- Reducing W thickness increases $\Delta\sigma_t$
- $\Delta\sigma_t$ can be diminished by selecting structural materials with:
  - lower expansion coefficient (steel F82H)
  - high thermal conductivity (Al5657)

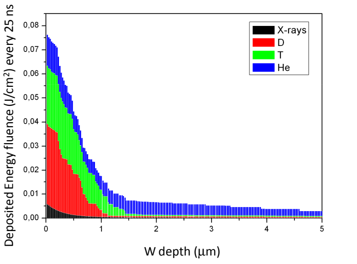
Irradiation conditions

For the studies presented in this work, we have chosen the product spectra of a 48 MJ shock ignition target [1,2]. The energy distribution of the most critical species is summarized in the left table. Figures down show the temporal and spatial energy deposition of X-rays, D, T, and He (10.7 MJ in about 2 µs) on first wall with W armor [3]. Carbon is not considered since its contribution is very dependent on the final target design.

Species	Energy (J)	%
X-rays	6.8×10^5	1.42
Neutrons	3.6×10^7	75.03
Deuterons	2.9×10^6	6.04
Tritons	3.5×10^6	7,29
He	3.6×10^6	7.5
C	1×10^6	2,08
Gamma rays H, 3He, 13C	3×10^5	0.63



Temporal profile of the energy deposition. Histograms correspond to time intervals of 25ns.

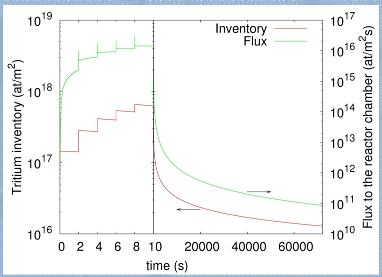


Spatial distribution of the deposited energy calculated using the SRIM code for ions and the absorption coefficient for X-rays

More than 50% of the total energy is deposited in the first µm of the W armor and 66% in the first 2 µm.

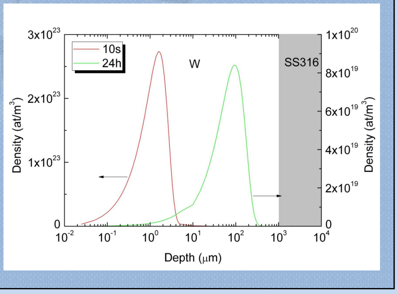
Tritium diffusion in the first wall

TMAP7 software is used to estimate diffusion of implanted tritium in the first wall. General equations for atomic diffusion into materials and recombination at the surfaces have been used.



- Tritium inventory increases with pulse number (~10^{17} at/m² per pulse) .
- 24 hours after the last shot, 98% of tritium escapes to the chamber.

- 10 s after the first shot a Tritium inventory of $6.28\cdot10^{17}$ at/m² is located at a d < 10 µm in W.
- 24 hours after the last shot a Tritium inventory of $1.29\cdot10^{16}$ at/m² is located at a d < 400 µm in W.



Conclusions

The first wall of the reactor chamber can survive the HiPER 4a conditions.

Thermo-mechanical and diffusion of tritium studies show that:

- T_{max} at inner surface are below melting point of W.
- To avoid plasticization in structural material the W thickness should be larger than 20 µm.
- Discontinuity in the tangential stress at interface is a key parameter to define armor thickness and the structural material type.
- Tritium accumulation in reactor chamber is well below regulation.
- Further calculations are needed to analyze diffusion into structural material.

REFERENCES:
[1] G. Zimmerman et al., Journal of the Optical Society of America 68 (1975) 549.
[2] J. Perkins. Internal report (http://www.docstoc.com/docs/54806737/Temperature-Response-and-Ion-Deposition-in-the-1-mm)
[3] J. Alvarez et al. Nuclear Fusion 51 (2011) 053019.

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